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④ Method for controlling the amount of moisture associated with a web of moving material.

⑤ A moisture measurement and control system controlling the amount of moisture in paper being manufactured by papermaking machinery, for example, linerboard, utilizes a standard scanning moisture sensor to calibrate a nonscanning moisture sensor to thus provide very fast and accurate moisture measurements for each zone of the moving paper. The measurement is communicated to a fast response time moisture profiler, for example, of the quartz heater type. In addition, the nonscanning moisture measurement unit, which utilizes capacitive electrodes, has improved accuracy due to its electrode arrangement and signal processing technique.

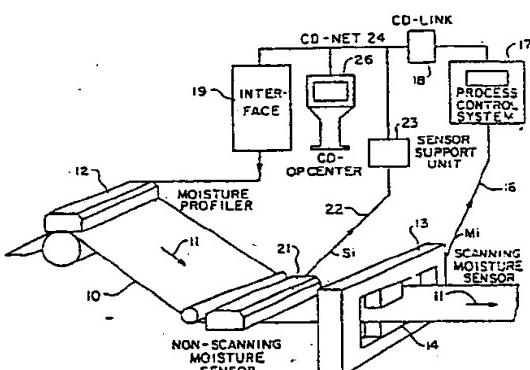


FIG. -1

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Description**METHOD FOR CONTROLLING THE AMOUNT OF MOISTURE ASSOCIATED WITH A WEB OF MOVING MATERIAL**

The present invention relates generally to a method for controlling the amount of moisture that is associated with a web of moving material and more specifically, to a method utilizing a fixed moisture sensor having a very fast response time.

The measurement of moisture in a moving web of, for example, paper, is presently being done by a scanning type moisture sensor utilizing an infrared frequency which is sensitive to the moisture in the paper. Although such sensor provides very accurate moisture values, in part because of the use of off-sheet standardization, its inherent nature due to the fact that it must scan means that there is a significant time delay between moisture measurements. For example, as much as thirty seconds between the measurement of moisture on each zone or slice of the moving paper can occur. When a type of sheet material, such as linerboard is being manufactured which may have rapid variations in moisture content, it is desirable to readjust the moisture content in a relatively short time -- for example, two seconds. This can theoretically be accomplished by the use of modern-day moisture profilers which utilize, for example, electrical heating elements of the quartz type to control the moisture content of the moving web. Such a type is manufactured by the assignee of the present invention under the trademark "INFRAPAC" and is illustrated in US-A-4573402.

Nonscanning moisture sensors are, of course, known such as that manufactured by Eur-Control of Sweden. This is a moisture sensor designed for use on a stand alone basis, to in effect replace the scanning moisture sensor. However, it is believed that its accuracy is relatively poor compared to the scanning moisture sensor. The capacitive type of sensor shown in the Eur-Control device is also illustrated in US-A-3,408,566 and US-A-3,684,953 assigned to Industrial Nucleonics Corporation.

It is therefore an object of the present invention to provide an improved method for controlling the amount of moisture that is associated with a web of moving material, with a rapid response time to measured moisture.

In accordance with the invention, there is provided a method using a fixed moisture sensor for controlling the amount of moisture that is associated with a web of moving material where a scanning moisture sensor scans across zones or slices of said web in a cross direction (CD) perpendicular to the machine direction of movement of said web to provide, sequentially, moisture values for each of said zones and also including a moisture profiler for controlling said amounts of moisture in said zones and having a response time much faster than the time required for a single cross direction scan by said scanning moisture sensor, said method comprising the following steps:

measuring the amount of moisture in each of said zones substantially continuously by use of a said fixed moisture sensor located at each zone;

calibrating said measured moisture by said fixed sensor by comparing with a said moisture value from said scanning moisture sensor to provide a calibration constant;

and utilizing said calibration constant by correcting said measured moisture from said fixed sensor to control said moisture profiler.

By way of example, an embodiment of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a block diagram showing the overall apparatus with which the method of the present invention is used.

Figure 2 is a cross sectional view of a nonscanning moisture sensor illustrated in Figure 1.

Figure 3 is a simplified plan view illustrating the nonscanning moisture sensor of Figure 1 and its communication connection to the remaining processing units of Figure 1.

Figure 4 is a plan view of one side of a printed circuitboard used in the moisture sensor of Figure 2.

Figure 5 is a plan view of the other side of a printed circuitboard of the moisture sensor used in Figure 2.

Figure 6 is a side view, simplified somewhat, of the printed circuitboard of Figures 4 and 5, showing the circuit pin connectors.

Figure 7 is a circuit schematic of the nonscanning moisture sensor of Figure 2.

Figure 8 is a flow chart used in performing the method of the present invention.

As illustrated in Figure 1, an object of the present invention is to control the moisture in the various slices or zones of the paper 10 being manufactured, for example, by a papermaking machine, which is moving in a machine direction, indicated by the arrows 11. As is well known in the papermaking process, in addition to removing gross amounts of moisture from the paper being manufactured to bring it to the desired quality level, it is also necessary to remove moisture streaks. These commonly occur in the machine direction -- perhaps over a width of one or two zones or slices. To accomplish this purpose a moisture profiler 12 is utilized which consists of a series of heating modules with quartz heating elements as illustrated in US-A-4,573,402.

Furthermore, a typical way of measuring the moisture is by the use of the scanning moisture sensor 13, which includes a pair of scanning heads 14 which, for example, every 30 seconds scan in a cross direction across the paper (perpendicular to machine direction 11) and provide by the use of a pair of infrared light

beams in a manner well known the sequential measurement of the moisture value of each zone or slice. Normally, the output of scanning moisture sensor 13 is coupled via line 16 to a process control system 17, and then via a cross direction link unit 18 and interface unit 19 to normally drive the moisture profiler 12 (and also a steam drum, not shown). However, as discussed above, if a fast response time is desired, this is very difficult to accomplish merely with the use of the scanning moisture sensor 13 which must scan across the sheet and in order to provide for proper calibration must go off sheet. Thus there is a time lapse of perhaps 30 seconds. This is very critical, especially where sheet material such as linerboard is being manufactured. Here, as little as a two second response time is desired. This is the time from which an unwanted moisture streak is sensed to the time when the moisture profiler 12 corrects this moisture streak by applying heat to that particular zone where the streak occurs. And a moisture profiler 12 of the type using electrical quartz heating elements inherently has the required faster response time.

Thus, in accordance with the method of the present invention there is provided a nonscanning or fixed moisture sensor 21 which, since it has a measuring element for each zone or slice of paper 10, in essence continuously provides a measurement S_I on the line 22 of the moisture in the various zones of paper 10. However, as discussed above, its accuracy is not as good as the scanning moisture sensor 13. Thus, the nonscanning or fixed sensor 21 cannot be utilized on a stand alone basis. The measured moisture output S_I on line 22 is coupled into a sensor support unit 23, which in turn is connected to a cross direction network 24. The cross direction network, as discussed previously, is the network for the signal M_I of the scanning moisture sensor 13, and interfaces with the process control system 17, the interface unit 19 of moisture profiler 12 and in addition, the cross direction operation center Unit 26.

The structural details of nonscanning moisture sensor 21 are more fully illustrated in the enlarged cross direction of Figure 2 which includes the sensor frame 31 carrying a sheet guide 32, below which the paper 10 moves in the direction 11. A moisture sensing unit 33 is indicated, which will be described in detail in the subsequent figures, which is mounted between a front wear strip 34 and rear wear strip 36. In general, a moisture sensing unit 33 presents a flat, smooth surface to the moving paper 10. In front of alternate units is a temperature sensor 37 used in the temperature compensation and linearization process.

Figure 3 illustrates the array of temperature sensor units 33 which extend substantially across the sheet. Each sensor 33 is connected via both a data bus 40 and address bus 42, along with the temperature sensor outputs from the units 37, to the sensor support unit 23 and then to the cross direction network bus 24. Information from each sensor unit 33 is obtained in a manner well known in the data processing art, by scanning across each sensor unit by addressing it on bus 42 and then reading out the data on bus 40. Since this is done by the high speed sensor support unit 23 which includes a typical microprocessor, in effect the amount of moisture being measured in each zone is a continuous measurement. That is the scanning time for the total cross direction of a sheet is in milliseconds.

The moisture sensing unit 33, indicated in Figure 2, is basically composed of a printed circuit board illustrated in Figures 4, 5 and 6. The board 41, as illustrated in Figure 4, is plated on the side facing the paper with transmit and receive capacitive electrodes of which the paper forms a part of the dielectric of the capacitor. The value of the capacitance C_x is proportional to the amount of moisture in the paper.

Then on the opposite side of the printed circuitboard 41, as illustrated in Figure 5, are additional reference and ground electrodes to complete the moisture measuring unit. Figure 6 illustrates the various pin electrodes used to connect the above printed electrodes.

Figures 4, 5, and 6 are illustrated in simplified form in Figure 7 which shows the actual electrical connections along with the effective capacitance which exists in the circuit. Referring to the top of Figure 7, there is the paper 10 which is illustrated and which has the capacitance C_x illustrated by the dashed capacitor. Then the moisture sensing element is illustrated at 33 with a printed circuitboard at 41, which has its top surface the transmit and receive electrodes so designated being potted by an epoxy dielectric layer 45 to provide a smooth surface. Each receive electrode is surrounded by a pair of transmit electrodes which are connected to the transmit line 43 driven by an oscillator 48. The receive line 44 on which the signal (Sig) is produced is connected to the receive electrode 44. The other electrical output of sensor unit 33 is an electrical connection designated reference (Ref) to a reference electrode 46 which is on the backside of printed circuitboard 41, as previously illustrated in Figure 5. In addition, there are a pair of surrounding ground electrodes or planes 47. The representations of the electrodes and their configurations in Figure 7 are simplified; thus Figures 4 and 5 must be referred to.

Very specifically and referring to Figure 5, the reference electrode for each sensing unit consists of four vertical plated areas 46 which lie in the center of the four receive areas with which they are juxtaposed (Figure 4). And then the ground plane, or conductor 47, is deposited or plated on the remaining portion of the back of circuitboard 41 to provide an effective shield or isolation for the transmit receive capacitive electrodes. That is, referring to Figure 2, this ground plane isolates the measuring elements from the remainder of the circuitry above it. The circuitry includes that shown in the remainder of Figure 7.

A source of electrical energy is provided by the oscillator 48 which provides a signal of amplitude A having a frequency of, for example, 500 kilohertz. This is coupled via the transmit line 43 to the transmit electrodes. And then through a ground on the receiving line 44 and capacitor C_6 the signal path is completed back to oscillator 48. Between the capacitive electrodes of the transmit and receive units, in addition to the capacitance C_x of the moisture carrying paper, there is the air capacitance C_1, C_2 in the dielectric epoxy layer 42, C_3 in the printed circuitboard 41, C_4 between the reference and transmit electrodes and the capacitance C_0 between the

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transmit electrode and the ground plane 47. The reference line is grounded through the external capacitance C_g . Only representational capacitances have been shown and of course, the same would occur between the other transmit and receive plates, as for example, C_1 , C_2 and C_3 . Thus, the indicated capacitors are intended to represent the entire capacitance of the particular moisture sensing unit 33.

5 The signals from the reference and signal lines are differenced in a unit 49 and synchronously demodulated at 52 to provide the measured moisture S_i at the output 53. This is coupled via amplifier 54 to multiplexer 56, which might typically be part of the sensor support unit 23. Then the output of this is sent to the cross direction net 24.

10 In order to provide the signal S_i that represents moisture content in paper 10, the signal must faithfully indicate the value of the capacitance C_x . Thus, the other capacitance values must be standardized or cancelled out and any temperature drift must be compensated for. It is noted that the capacitor C_4 is proportional to C_2 plus C_3 for all temperatures.

15 The equations page following this description illustrates how the differencing of the reference and signal outputs of the moisture sensor 33 by unit 49 provides a signal representing capacitance C_x in paper 10 and thus an indication of moisture content of that paper for the particular zone over which the moisture sensing element is located.

20 In equations 1 and 2, the electrical signals designated "Ref" and "Sig" are shown as being dependent on twice the amplitude A, the oscillator output, and the combination of the various capacitors illustrated in Figure 7.

25 Equations 3 and 4 are rearrangements of equations 1 and 2. Then by assuming the conditions of equations 5 and 6, equations 3 and 4 simplify into equations 7 and 8. Then in equation 9, a choice of the value of the capacitor C_g (which is on the reference line of Figure 7) is made so that the ratio of C_4 to C_g is approximately equal to the ratio combination illustrated in the equation. From a practical standpoint, this is done by measuring the signal output with no paper in the gap of the capacitive electrodes and then bringing the signal S_i to '0.' Note that, as discussed above, C_4 varies with temperature in the same manner as C_2 and C_3 . Thus choosing this ratio cancels out or effectively tracks the temperature variation.

30 Finally, equation 10 is the result of the operation of the differencing unit 49, subtracting the reference from the signal, to produce a signal S_i which is the ratio of the paper capacitance C_x and the external capacitance C_g on the signal line. The addition of the external capacitance C_g and its adjustment provides a desired null signal as illustrated by equation 9 to cancel out the effects of the other electrode capacitances.

35 The overall method is illustrated by the flow chart of Figure 8 where, in the step 61, the amount of moisture M_{in} each of the zones is measured by the scanning sensor at zone i. And then in step 62 the moisture signal S_i is also measured by the fixed sensor. Then the S_i signal is temperature compensated and linearized, as shown in step 63, by sensing the temperature T_i at that zone by the associated temperature sensor 37 (see Figures 2 and 3) and by using the signal value S_0 measured with no paper near the sensor; this is achieved by actually lifting the sensor from the paper. In step 64 a calibration constant is calculated by comparing the signal value X_i with the scanning sensor value, M_i , to provide a calibration constant, K_i . Since it is assumed that the scanning moisture sensors are much more accurate than the fixed or nonscanning moisture sensor, this is in essence an error correction factor.

40 The above calibration constant, K_i , for this particular zone is stored and then in step 66 for subsequent zones in time and in the same machine direction moisture MOI_i is determined by taking the linearized compensated value of S_i , that is, X_i , and multiplying it by the calibration constant K_i as illustrated. This final corrected value is then used in the interface unit 19, Figure 1, to drive the moisture profiler 12, as shown in step 67.

45 Since scanning unit 13 is being used to calibrate fixed sensor 21, the two sensors should be located close enough, e.g., 1 foot, so there is no appreciable change in moisture. However, a uniform or predictable change can be easily compensated.

50 Thus, the present invention has provided a moisture control method which has a rapid response to change of moisture content in, for example, linerboard. This has been achieved with high accuracy by linking of the nonscanning moisture sensor with the scanning moisture sensor in the manner described above. In addition, the nonscanning moisture sensor itself has improved operation due to the cancelling out of the effects of various stray capacitances by the differencing technique and the electrode arrangement.

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EQUATIONS

$$1) \quad \text{Ref} = 2A \frac{1}{1 + C_g/C_4}$$

$$2) \quad \text{Sig} = 2A \frac{1}{1 + \frac{C_6}{C_x + C_1 + C_2 + C_3}}$$

$$3) \quad \text{Ref} = 2A \frac{C_4}{C_g + C_4}$$

$$4) \quad \text{Sig} = 2A \frac{C_x + C_1 + C_2 + C_3}{C_x + C_1 + C_2 + C_3 + C_6}$$

$$5) \quad C_g \gg C_4$$

$$6) \quad C_6 \gg C_x + C_1 + C_2 + C_3$$

$$7) \quad \text{Ref} = 2A \frac{C_4}{C_g}$$

$$8) \quad \text{Sig} = 2A \frac{C_x + C_1 + C_2 + C_3}{C_6}$$

$$9) \quad \text{Choose } \frac{C_4}{C_g} = \frac{C_1 + C_2 + C_3}{C_6}$$

$$10) \quad \text{Sig - Ref} \approx 2A \frac{C_x}{C_6}$$

Claims

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1. A method using a fixed moisture sensor for controlling the amount of moisture that is associated with a web of moving material where a scanning moisture sensor scans across zones or slices of said web in a cross direction (CD) perpendicular to the machine direction of movement of said web to provide, sequentially, moisture values for each of said zones and also including a moisture profiler for controlling said amounts of moisture in said zones and having a response time much faster than the time required for a single cross direction scan by said scanning moisture sensor, said method comprising the following steps:

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measuring the amount of moisture in each of said zones substantially continuously by use of a said fixed moisture sensor located at each zone;

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calibrating said measured moisture by said fixed sensor by comparing with a said moisture value from said scanning moisture sensor to provide a calibration constant;

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and utilizing said calibration constant by correcting said measured moisture from said fixed sensor to control said moisture profiler.

2. A method as in Claim 1 where said fixed moisture sensor includes capacitive electrodes and a juxtaposed reference electrode and where said step of measuring said amounts of moisture by said fixed sensor includes the step of differencing signals from said capacitive electrodes and said reference electrode.

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3. A method as in Claim 2, including the step of adding external capacitance to said reference electrode to provide a null signal.

4. A method as in Claim 2 or Claim 3, including the step of providing a ground plane for said capacitive electrodes for electrical isolation.

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5. A method as in Claim 3 or Claim 4, where said external capacitance is ratioed against a reference electrode to capacitive electrode capacitance which varies with temperature proportionately with the capacitance of said capacitive electrodes themselves.

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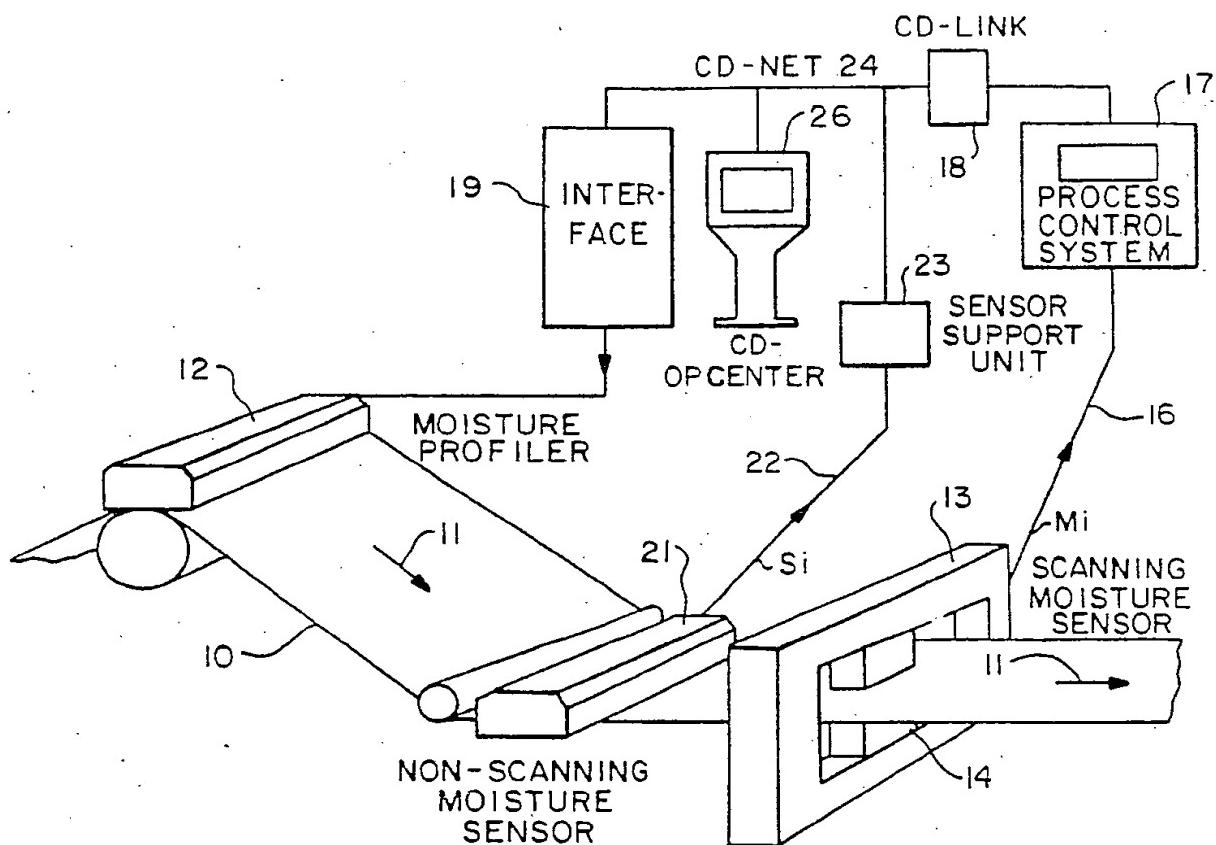


FIG. - 1

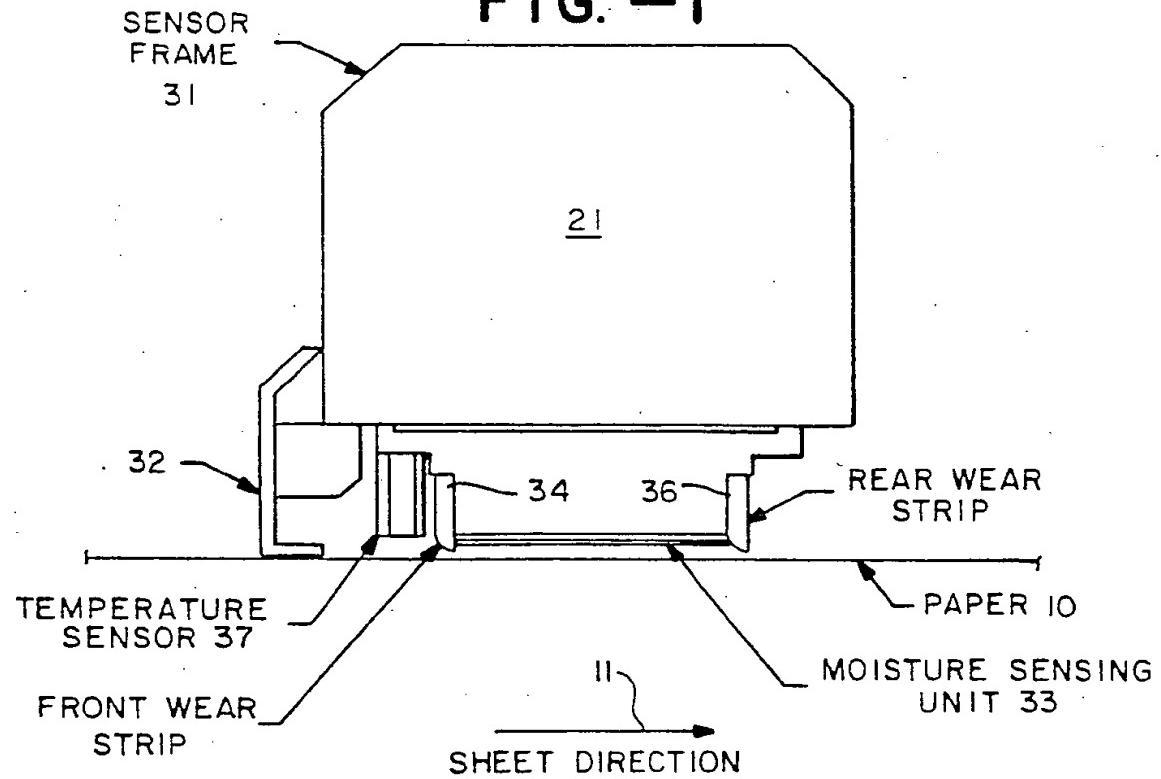


FIG. - 2

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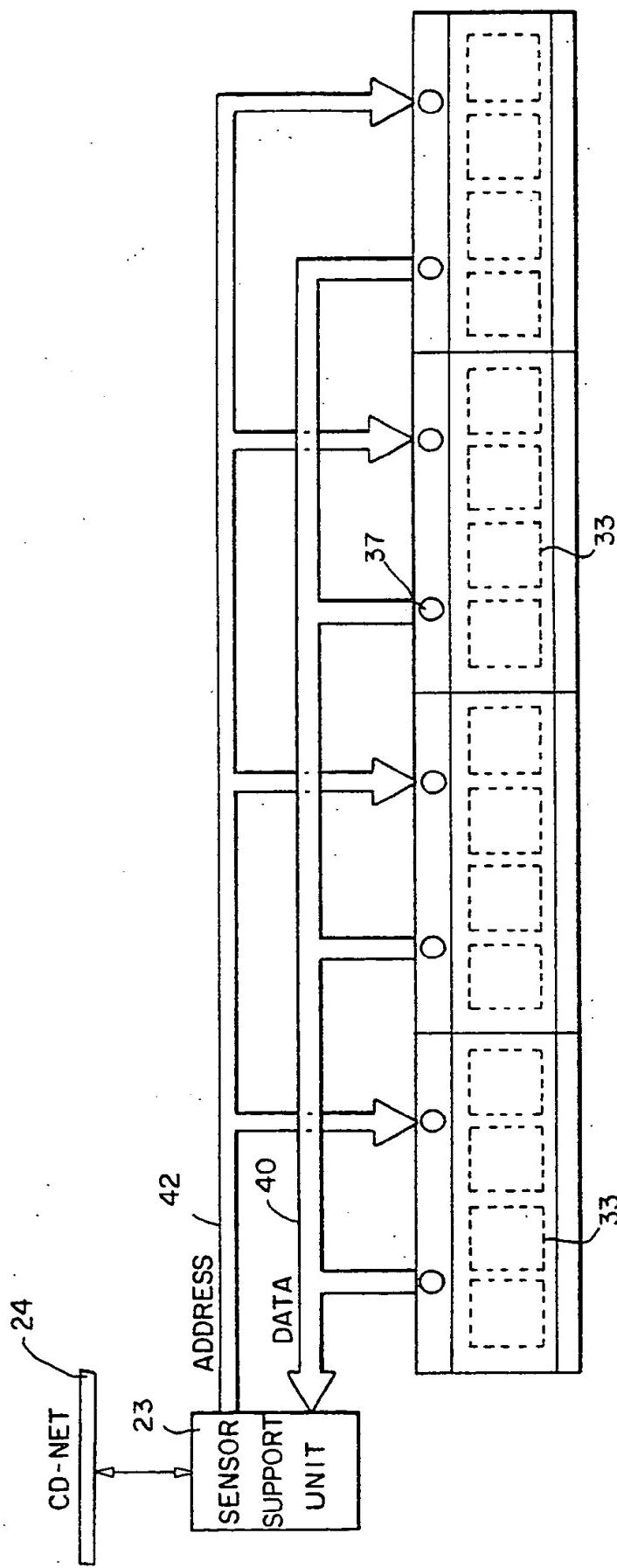


FIG. - 3

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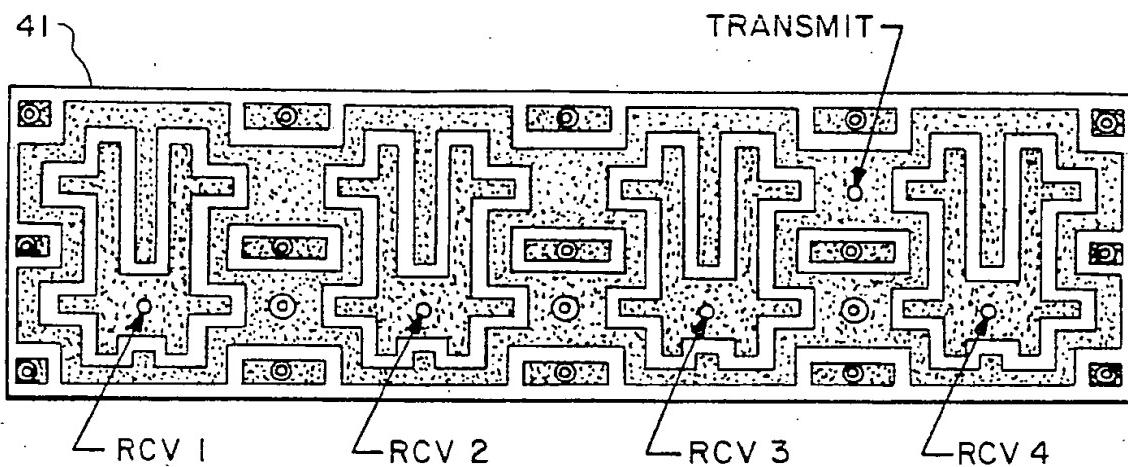


FIG. - 4

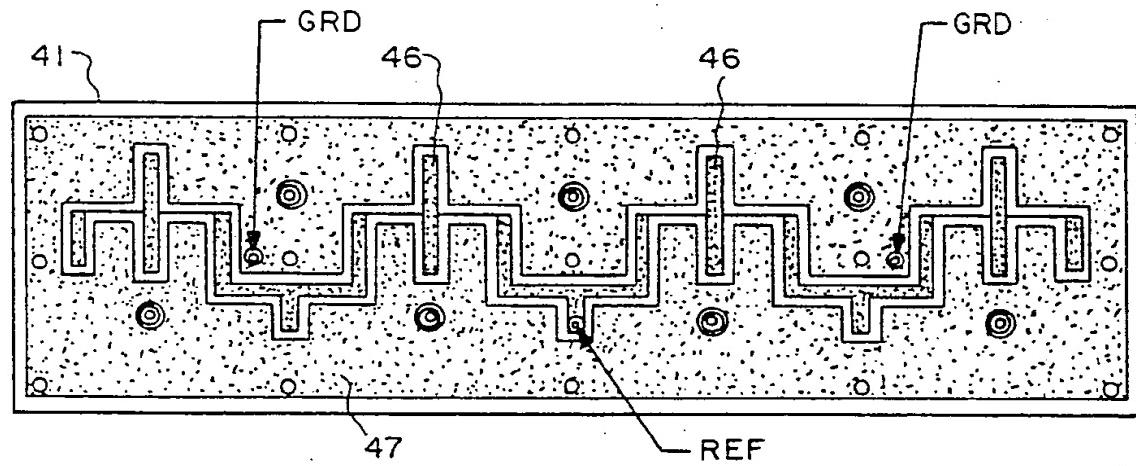


FIG. - 5

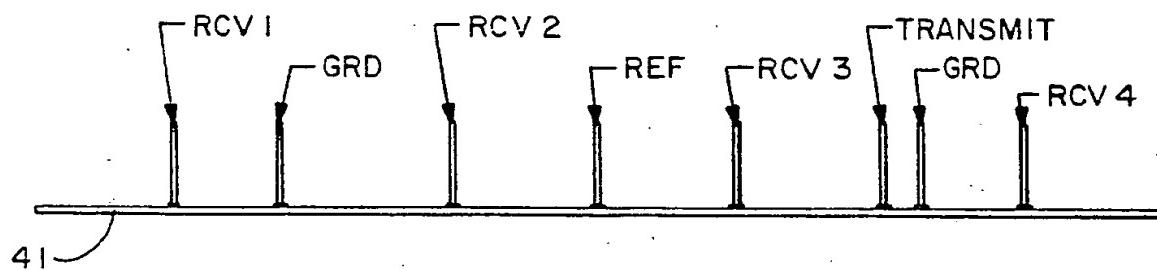


FIG. - 6

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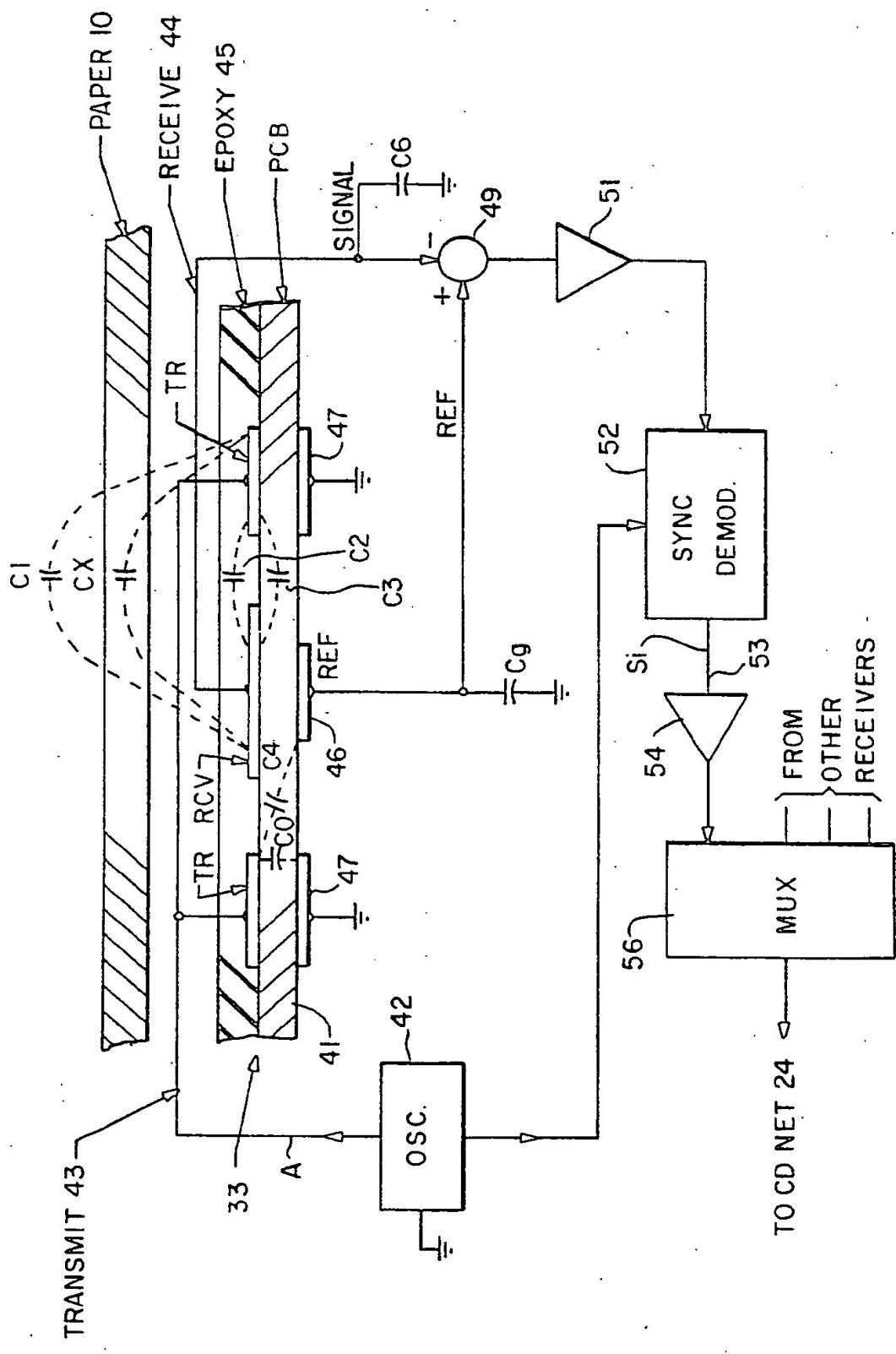


FIG. - 7

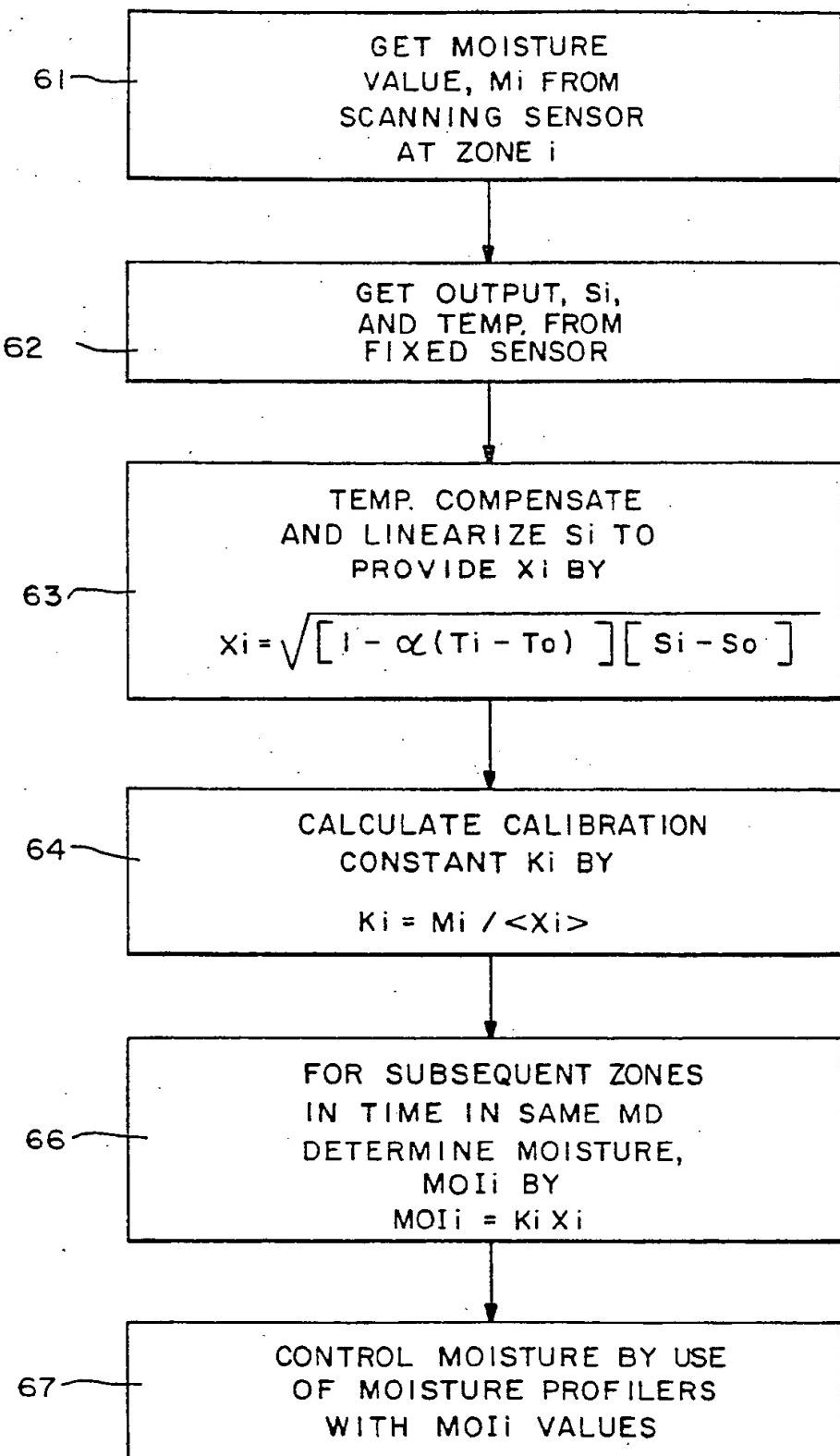


FIG. — 8

